Future Reactor Neutrino Oscillation Experiments at Krasnoyarsk

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Recent studies of atmospheric neutrinos and the results from CHOOZ and Palo-Verde experiment call for new and more sensitive searches for neutrino oscillations at reactors. The main goal of the project considered here is to look for very small mixing angle oscillations of electron neutrinos in the atmospheric neutrino mass parameter region around $\Delta m^2 \sim 3\times10^{-3} eV^2$ and to define the element U_{e3} of the neutrino mixing matrix (U_{e3} is the contribution of the mass-3 state to the electron neutrino flavor state). The practical goal of the project is to decrease, relative to the CHOOZ, the statistic and systematic errors as much as possible. To achieve this we plan to use two identical antineutrino detectors each with a $\sim$ 50-ton liquid scintillator target located at $\sim$1100 m and $\sim$250 m from the underground reactor ($\sim$ 600 mwe). Much attention is given to the detector calibration and monitoring procedures. As a first step we consider two much smaller pilot detectors each of $\sim$ a 3 ton target mass stationed at $\sim$20 m and 35$-$60 m from the reactor. The goals of this first stage are: (i) to accumulate necessary experience and (ii) to investigate with electron neutrinos the LSND mass parameter region.

1. INTRODUCTION

The $\sim$ 1 km baseline reactor experiments CHOOZ [1] and Palo Verde [2] have searched for electron antineutrino disappearance in the atmospheric mass parameter region ($\Delta m^2 \sim 3\times10^{-3} eV^2$) using the $\bar{\nu}_e + p \to e^+ + n$ process as a detection reaction. No signs of oscillations have been found:

$$\sin^2 2\theta_{CHOOZ} \leq O.1$$
$$(at \quad \Delta m^2 = 3\times10^{-3} eV^2). \quad (1)$$

The Super Kamiokande data reported at this Conference [3] confirm the evidence in favor of intensive ($\sin^2 2\theta_{SK} \approx 1$) $\nu_\mu \to \nu_x (x \neq e)$ transitions. In the three active neutrino mixing model considered here $\nu_\mu = \nu_\tau$.

The negative results of the CHOOZ experiment has important positive meaning that the contribution $U_{e3}(= \sin\theta_{13})$ of mass-3 eigenstate to the ν_e flavor state is not large:

$$U_{e3} \leq 2.3\times10^{-2} \quad (2)$$

(We remember that $\sin^2 2\theta_{CHOOZ} = 4U_{e3}{}^2(1-U_{e3}{}^2) \approx 4U_{e3}{}^2$, see for example [4]).

In this report we consider a new reactor experiment Kr2Det aimed for much more sensitive search of neutrino oscillations in the Δm^2_{atm} mass parameter region. The main physical goals of the search are:

- To obtain new information on the electron neutrino mass structure (U_{e3}),
- To provide normalization for future long baseline experiments at accelerators,
- To achieve better understanding of the role ν_e can play in the atmospheric neutrino anomaly.

It is interesting to note that measurement of U_{e3} can help to choose between possible solar neutrino oscillation solutions [5]

Other physical potentialities of the project (test of the LSND results, search for the ster-

ile neutrinos) are considered elsewhere. In the next Section we briefly review factors, which limited the sensitivity of the CHOOZ results and then go to the Kr2Det project.

2. THE CHOOZ EXPERIMENT

The CHOOZ detector was built in an underground gallery (300 mwe) at a distance of about 1 km from two PWR type reactors of total rated power 8.5 GW (th). Using e^+, n delayed coincidence technique total about 2500 neutrino interactions were detected in the 5-ton liquid scintillator target. The neutrino and background detection rates, N_ν and N_{BKG} , were measured to be (typically) 12 (d^{-1}) and 1.6 (d^{-1}). The ratio $R_{meas/calc}$ of measured to calculated for no-oscillation case neutrino rates was found to be

$$R_{meas/calc} = 1.01 \pm 2.8\%(stat) \pm 2.7\%(syst), \qquad (3)$$

The ratio of measured to expected positron spectra $S_{meas}/S_{expected}$ is presented in Fig.1.a

The CHOOZ oscillation limits (Fig.2) have been derived using an absolute method of analysis. All available experimental information has been compared to the expected no-oscillation values. The results of the analysis directly depend on the correct determination of the reactor power, absolute value of the $\bar{\nu}_e$ flux and their energy spectrum, nuclear fuel burn up effects, knowledge of the neutrino detection efficiency, absolute number of protons in the neutrino target and detector spectral response characteristics.

We would like to note here that CHOOZ experiment has demonstrated a revolutionary improvement on the neutrino detection technique: The level of the background at CHOOZ is hundreds times lower than has ever been achieved in any of the previous neutrino experiments at reactors. The underground position of the detector has sufficiently reduced the flux of cosmic muons, which is the main source of the correlated background and separation of the PM's from the neutrino target has reduced the accidentals coming from the radioactivity of the PM glass.

3. FUTURE KRASNOYARSK TWO DETECTOR EXPERIMENT Kr2Det

3.1. Main features of the approach

(i) Relative to CHOOZ, we plan to increase the statistics of detected neutrinos by a factor of ~ 20: $N_{\nu Kr2Det} \sim 20 N_{\nu CHOOZ}$. To achieve this we increase the mass of the liquid scintillator target up to 50 ton. (ii) To retain CHOOZ good effect to background ratio the detector is placed in an underground position. The overburden at Krasnoyarsk is 600 m.w.e., which is twice as much as at the CHOOZ laboratory. To suppress the external gammas we chose a miniature version of the KAMLAND detector design with a ~ 1 m thick layer of no-scintillating oil between the PM's and target volume (Fig.3). (iii) To eliminate most of the systematic uncertainties we turn to the idea of purely relative measurements and consider two identical scintillation spectrometers (far and near) stationed at 1100 and 250 m from the reactor. (iiii) To control remaining systematics special detector intercomparison procedures are being developed. In Table 1 are presented some of (expected) parameters of the Kr2Det and of the CHOOZ experiments.

Table 1
Kr2Det & CHOOZ, neutrino detection rates and backgrounds

Parameter	Distance (m)	M.W.E.	Target mass (ton)	$\bar{\nu}_e (d^{-1})$	BKG (d^{-1})
Kr2Det Far	1100	600	50	50	5
Kr2Det Near	250	600	50	1000	5
CHOOZ	1100	300	5	12	1.6

With a rate of 50 $\bar{\nu}_e$/day the desired total 40-50 thousand neutrino events can be accumulated in an acceptable time of data taking.

3.2. Data analysis and detector calibrations

In no-oscillation case the ratio of the two simultaneously measured positron energy spectra S_{FAR}/S_{NEAR} is energy independent (Fig. 1b). Small deviations from the constant value of this ratio

$$S_{FAR}/S_{NEAR} = C(1 - \sin^2 2\theta \sin^2 \phi_F) \times (1 - \sin^2 2\theta \sin^2 \phi_N)^{-1} \quad (4)$$

are searched for oscillations ($\phi_{F,N}$ stands for $1.27\Delta m^2 L_{F,N}/E_\nu$, and $L_{F,N}$ are the distances between the reactor and detectors). The results of the analysis are independent of the exact knowledge of neutrino flux and their energy spectrum, burn up effects, the numbers of target protons, neutrino detection efficiencies: However the relative difference of the detector energy scales should be strictly controlled.

Calibration of the detectors is a key problem of the experiment considered here. Small difference of the response functions of the two detectors, which is difficult to avoid, can distort the ratio (4) and mimic (or conceal) the oscillation effect. The goal of the calibration procedures we consider is to measure sensitively this difference and introduce necessary corrections. This can be done by a combination of different methods. First we consider periodic control of the energy scales in many points using γ-sources shown in Fig. 4. Second method uses a small ^{252}Cf spontaneous fission source placed in the detector's centers. The source generates continuous spectrum due to neutron recoils and prompt fission gammas also shown in Fig. 4. Any deviation from unity of the ratio of the spectra measured in two detectors can be used to calculate corrections under consideration. A useful monitoring of the scales at 2.23 MeV can also provide neutrons produced by through going muons captured by scintillator protons during the veto time.

3.3. Expected constraints

Expected 90% CL oscillation limits can be seen in Fig.2. It was assumed that 40 000 $\bar{\nu}_e$ are detected in the detector stationed at 1100 m from the reactor and that the detector spectrometric difference is controlled down to 0.5%.

4. CONCLUSIONS

Mass structure of the electron neutrino can sensitively be explored using two detector techniques. The results will also give useful normalization for future long baseline oscillation experiments at accelerators. The Kr2Det experiment is relatively inexpensive when compared to already running projects such as KAMLAND where neutrino target of

a 1000 ton mass is used.

5. Acknowledgements

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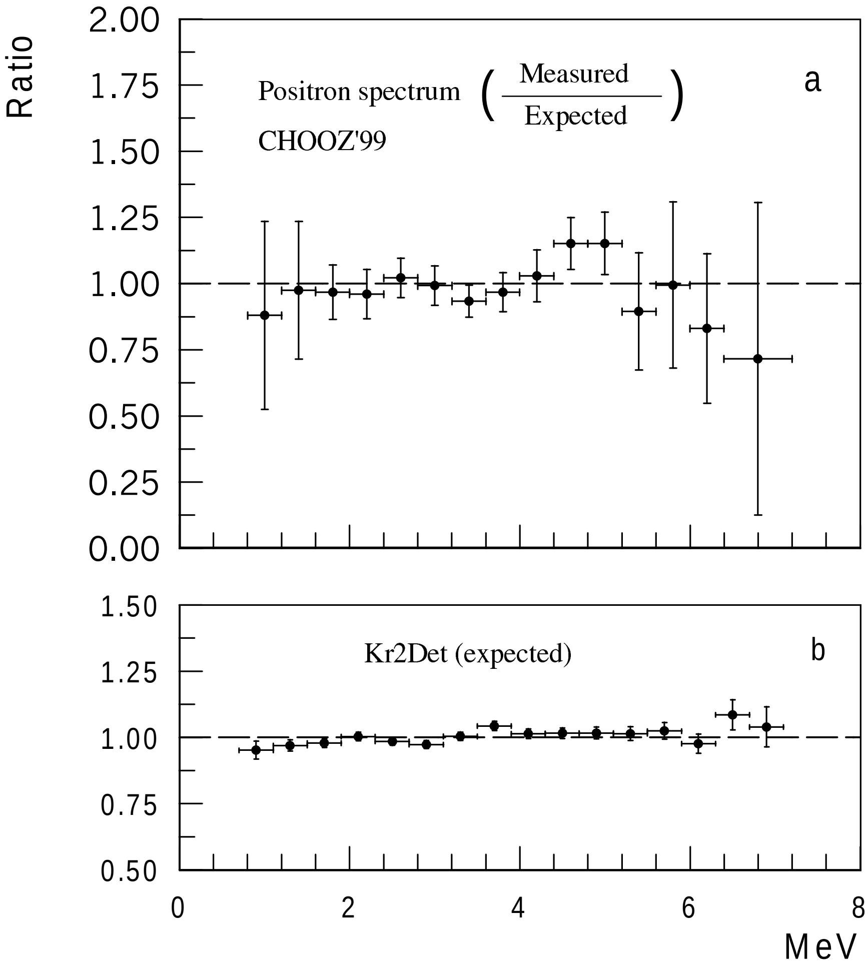
FIGURES

Figure 1. Ratios of positron spectra.
a) CHOOZ: Ratio of measured to expected in no-oscillation case.
b) Kr2Det : far to near (MC simulation, no-oscillations, normalized to unit).

Figure 2. Reactor neutrino oscillation parameter plots. "CHOOZ'99", "Palo-Verde 2000" and "Kr2Det" (expected)are 90% CL $\bar{\nu}_e$ disappearance limits. The shaded area is Super Kamiokande 2000 allowed $\nu_\mu \to \nu_\tau$ oscillation region.

Figure 3. The Kr2Det detector.
1- Neutrino target, 50 ton mineral oil (PPO),
2 - mineral oil (buffer),
3 - transparent film,
4 - PMTs, 5 - veto zone.

Figure 4. Sources for detector calibrations. The solid line is the positron energy spectrum, the dashed line is the spectrum generated by Cf source.



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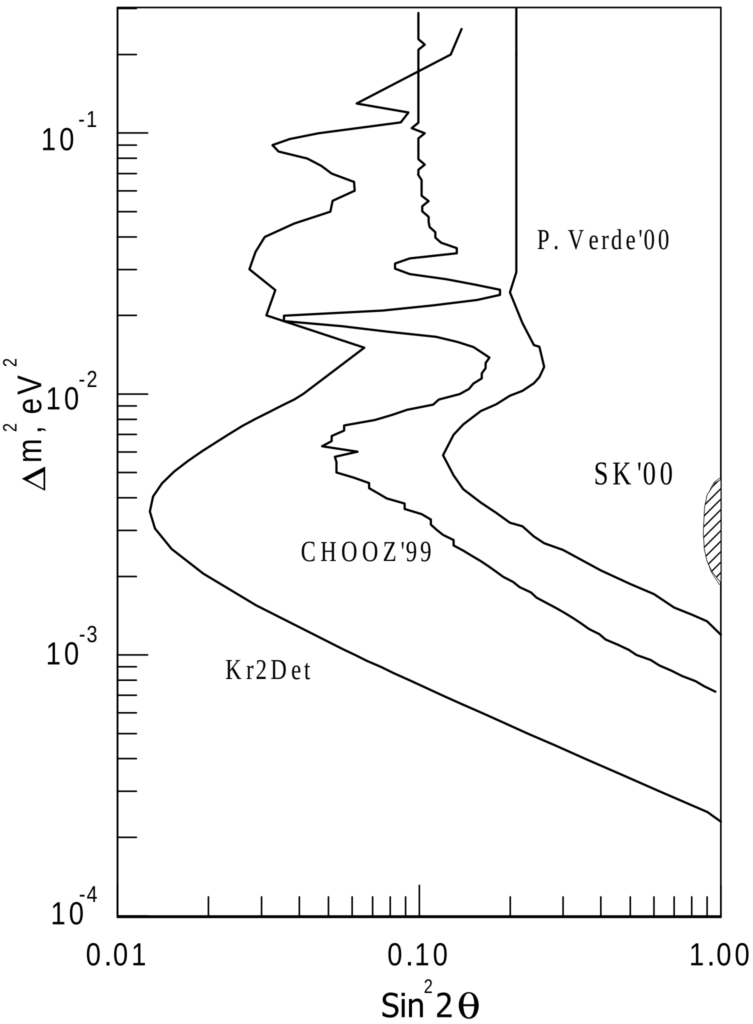

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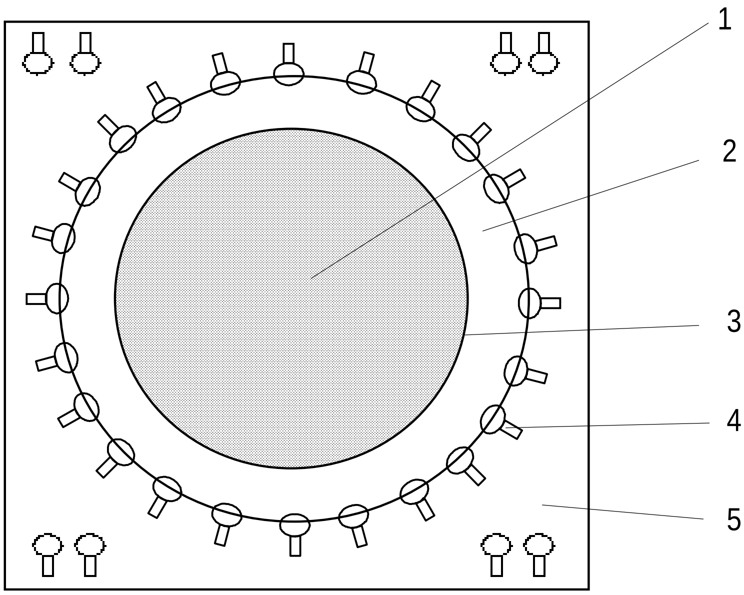
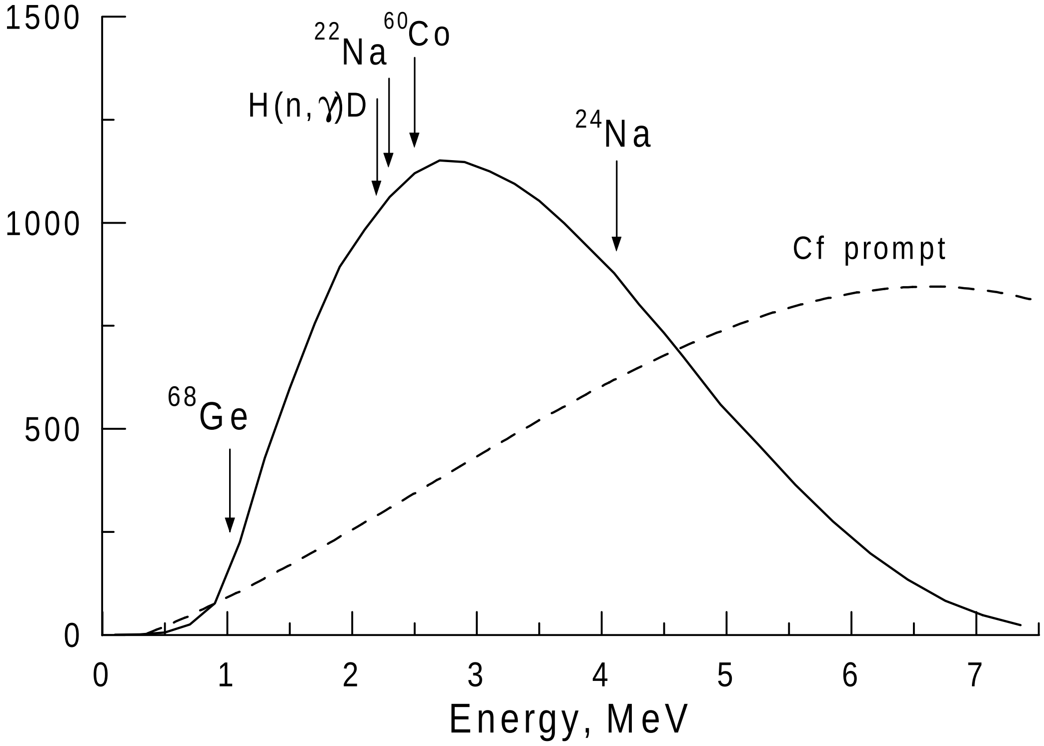


Figure 3. The Kr2Det detector (schematic).

1 - The neutrino target (50 ton mineral oil + PPO).
2 - Mineral oil.
3 - The transparent film.
4 - The PMTs.
5 - Veto zone



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